THE UNIVERSITY OF ALBERTA

HEAT BUILD-UP AND RETENTION IN SELECTED TYPES OF HOCKEY HELMETS

by

© GUY HENRY

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES

IN PARTIAL FULFILMENT OF THE REQUIREMENTS

FOR THE DEGREE OF MASTER OF ARTS

FACULTY OF PHYSICAL EDUCATION

EDMONTON, ALBERTA

FALL, 1969

THE UNIVERSITY OF ALBERTA

FACULTY OF GRADUATE STUDIES

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies for acceptance, a thesis entitled "Heat Build-Up and Retention in Selected Types of Hockey Helmets," submitted by Guy D. Henry in partial fulfilment of the requirements for the degree of Master of Arts.

ABSTRACT

The purpose of this study was to compare ten commercial hockey helmets on the basis of temperature build-up and heat dissipating qualities. The helmets were fitted onto a copper manikin which was clamped upright on a laboratory stand. The head was filled with water which was maintained at a required temperature by a quartz immersion heater and a thermister. The helmets were tested at three required temperatures and a fan was used to enable each helmet to dissipate heat according to its individual ventilation design. Thermocouples placed at six specified positions registered temperature changes which were recorded on a Milivolt Potentiometer. The hockey helmets were evaluated on the basis of two parameters: the extent of temperature build-up and retention, and the ability to dissipate heat readily.

There was significant difference in heat retention and heat dissipating capacities of the ten helmets. Helmets varied according to temperature and with the effect of the fan. No significant difference between the helmets was found for different temperature readings at the six specified positions. The helmets which recorded the lowest temperature build-up and dissipated heat most readily were sparsely insulated and made least contact with the manikin head.

ACKNOWLEDGEMENTS

The author wishes to extend his appreciation to his committee members, Dr. S. Mendryk (Chairman), Dr. C. M. Rodkiewicz, Dr. R. B. Wilberg, and Professor C. J. Drake, for their guidance and assistance.

The writer would also like to acknowledge the financial assistance provided by the Faculty of Physical Education in the construction of the apparatus.

Sincere thanks goes to Pat Bates who typed this thesis and who was always a constant source of encouragement.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

STATEMENT OF THE PROBLEM

Introduction

The importance of wearing protective equipment in hockey is primarily to prevent injury. The beneficial aspects are undermined by such detrimental factors as heat build-up and retention, weight, and limiting range of motion. The head, being the most vital part of the body, necessitates protection. Nevertheless, hockey players refuse to wear helmets due to excess perspiration and warmth causing discomfort. The design and style of various helmets as well as the type of material used in the lining differ considerably which accounts for the variance in the heat dissipation capacity.

Hockey is the fastest game in the world even though the players are burdened with cumbersome equipment and confined to a relatively limited playing area. However, the number of injuries is quite low. This fact is supported by Thorndike (1) who compiled records of seasonal injuries over a period of seven years at Harvard University. The incidence of injury in contact sports tends to be higher during the fall and winter seasons. Hockey can be classified as a winter contact sport; nevertheless the accident rate is only 145 per thousand participants whereas the fall accident rate, with football being the predominant contact sport, is 620 per thousand. The low incidence of injury nevertheless does not exclude the importance of testing the effectiveness of protective equipment, particularly the various types of hockey helmets.

A brief review of literature indicates that the head seems to be the most susceptible injury region. In a survey involving 2,469 children aged seven to eighteen years conducted in the Toronto Township Hockey League in the spring of 1963 and during the 1963-64 hockey season, it was found that 67.5 percent of the injuries were to the face and head whereas 32.5 percent were to the rest of the body. (2) In another hockey study conducted in the city of Red Deer (3) involving 107 individuals aged twelve to fourteen, it was found that 58 percent of the accidents were to the head and only 42 percent to the rest of the body. Of the total number of forty-one hockey injuries recorded in the intramural program at The University of Alberta (4), thirty were to the head and face and only eleven to the body.

It is apparent from these three studies that the head and facial areas are more vulnerable to injuries; nevertheless the wearing of hockey helmets is only mandatory up to the juvenile level. Injuries are quite prevalent in the National Hockey League. This fact is supported in part by an article dealing with injuries stating that approximately fifteen to twenty concussions occur annually. (5)

Hockey players are reluctant to wear helmets mainly because of the discomfort of excess perspiration and heat build-up. Heat dissipation varies with the different ventilation designs of each helmet. The transmission of heat occurs by conduction, convection, and radiation. In most situations, especially in nature, heat flows by several of these mechanisms. When the body temperature is over 80°F., evaporation of perspiration is the most effective means of dissipating heat. (6)

Conduction can be described as a process by which heat flows from a region of higher temperature to a region of lower temperature within a medium (solid, liquid, gaseous) or between mediums in direct physical contact. When molecules in one region acquire a mean kinetic energy greater than that of molecules in an adjacent region, as seen in a difference in temperature, the molecules possessing the greater energy will transmit part of this energy to the molecules in the lower temperature region.

Another means of heat transmission is by radiation. This is a process by which net heat flows from a high temperature body to a body at a lower temperature when the bodies are separated in space, even when a vacuum exists between them. Radiation and absorption is a universal process of energy transfer. The energy in transit through space is called radiant energy.

The last means of heat transmission occurs through a process called convection. Convection is a process of energy transport by the combined action of heat conduction, energy storage and mixing motion. (7)

The Problem

The purpose of this study is to examine and evaluate the heat build-up and heat dissipation at six specified sites in selected types of hockey helmets.

Definition of Terms

Surface Temperature. The temperature, in Fahrenheit degrees, as measured by copper constantan thermocouples placed at various sites in the helmet.

Heat Transfer. Defined as the transmission of energy from one region to another as a result of a temperature difference between regions.

Thermal Conductivity (k). The amount of heat a material transfers per unit area, per unit time, per unit temperature gradient. In the British system, thermal conductivity is usually expressed in BTU/ft^2 hr. F^o /in.

Temperature Gradient. Is the temperature difference per unit distance along the direction of heat flow.

Electro-Motive Force. Is the difference in potential between two points in an electric circuit.

Thermocouple. Defined as a pair of dissimilar electrical conductors, so joined as to produce a thermal E.M.F. when the junctions are at different temperatures.

REFERENCES

1. Thorndike, A. "Treatment of the More Common Athletic Injuries," Medical Clinics of North America, 34:1255-1269, 1950.

2. Toogood, T., W. G. Love. "Hockey Injury Survey," Journal of the Canadian Association for Health, Physical Education and Recreation, 32:20-23, (Jan.) 1966.

3. White, C. A. Personal Correspondence, March 1967.

4. Intramural Accident Report Files, Faculty of Physical Education, The University of Alberta, 1968.

5. "Hockey," Life, (February 2, 1968), p. 49.

6. Minard, D., H. S. Bolding, and J. R. Kingston. "Prevention of Heat Casualties," Journal of American Medical Association, 165:1813, 1957.

7. Kreith, F. Principles of Heat Transfer, International Textbook Co., Scranton, Pennsylvania, 1962, pp. 3-8.

CHAPTER II

REVIEW OF THE LITERATURE

A perusal of the literature has failed to reveal any directly related information regarding temperature build-up in any type of protective head gear. There are, however, several studies and references that pertain indirectly to the problem of heat build-up and retention in hockey helmets.

In a study conducted by Stoll and Hardy (1) it was found that temperature on the forehead increased with pressure. A contact force of 20 grams, which is equivalent to 165 mm. Hg., caused a rise in temperature of approximately 2°C. over the average temperature under minimal pressure. When a thermocouple was just touching the forehead ("zero" contact pressure) the readings varied about ±0.5°C. With a pressure of 10 gm./9 mm.^{2} (1.1 gm./mm.^{2}) the temperature rose sharply about 1.5°C. Thereafter it fell slowly, fluctuating about ±0.1°C. as it dropped. With an increase in pressure of 20 gm./9 mm.^{2} (2.2 gm./mm.^{2}) the temperature rose immediately to a level where it remained constant within ±0.04°C. The pressure required to get a constant reading must exceed the capillary, diastolic and normal systolic blood pressure. When the pressure was removed, the temperature dropped a full degree Centigrade where it fluctuated, as before, under zero pressure. The higher temperature recorded is due to the fact that the skin is compressed between the thermocouple and the deeper tissues that hold higher temperature. Therefore, the temperatures observed under these

conditions are those found at some depth beneath the compressed skin.

The evaporation of perspiration and cooling in a football uniform is a major problem in the dissipation of heat. The heat transfer characteristics of a typical football uniform were measured by Goldman (2) using a heated copper manikin. It was found impossible to design a uniform with better evaporative value without reducing the protection against abrasion or concussion. The substitution of another "armour" material instead of the plastic protective pads would not improve the impermeable characteristics of these pads. The suggestion that perhaps the plastic pads could be perforated is not feasible because research conducted on perforating impermeable materials with various sizes and number of holes to improve heat transfer all suggests that at least fifty percent of the impermeable area must be open (3). Furthermore, a plastic pad with a fifty percent void area will not likely be strong enough to withstand the impact involved in contact sports.

Moore (4) studied the colours of different crash helmets that were exposed to the sun over varying time intervals. Results showed that the temperature in padding material in a black helmet, worn by a seated subject on a sunny day, rose from 20^{o}C. to more than 50^{o}C. in twenty-two minutes; under the same conditions a white helmet rose to only 37^{o}C. The author concluded that there were considerable advantages from the comfort point of view in a white helmet but more important, that helmets should be made to withstand a considerable range of temperatures without loss of protective and wearing qualities.

Heat Transfer

Energy is transferred when a temperature gradient exists within a system. This type of energy transportation is known as heat transfer. The heat flow is a process by which the internal energy of a system is changed.

Thermodynamics is a branch of science which deals with the relation between heat and other forms of energy. There are certain principles or laws which govern thermodynamics and these are:

1. Energy can be neither created nor destroyed but only changed from one form to another. This first law governs all energy transformations quantitatively but places no restrictions on the direction magnitude of the transformation.
2. No process is possible whose sole result is the net transfer of heat from a region of lower temperature to a region of higher temperature.

Heat transfer processes involving the transfer and conversion of energy must obey the first and second laws of thermodynamics (5).

Insulation

The insulation or padding inside hockey helmets is a major factor in heat dissipation or retention. The style and shape of insulation used is a foam type material. This material or padding has an impact absorption effect but is a very poor heat conductor. This insulating effect is due mainly to the air in the pores, which as a gas, is a poor conductor of heat. The body density of a porous or fibrous substance, which is defined as the ratio of its total mass to its total volume, is

very small because of the large number of air voids. As the density of an insulating material becomes smaller an equal decrease in the heat conductivity occurs. If water penetrates into a porous substance and fills the pores, for example, excessive perspiration inside a hockey helmet, the insulation does not have the same effect due to the content of water and therefore takes on a higher thermal conductivity value. The size of the air pores is very significant. Insulating materials with large air spaces have a different insulating effect than do materials with small pores because the air circulating within the large free spaces will decrease the insulating effectiveness of the material. Also, given the same temperature range, more heat is dissipated by radiation through insulation with large air spaces than through material with the same volume with small air spaces (6).

Heat Flow in Metals

Pure metals are the best heat conductors. Electrons are the major carriers of heat and thermal conductivity is related to electric conductivity which decreases with increasing temperature (6). If a metal is heated to a high temperature at one end, the electrons acquire a velocity of thermal agitation higher than the average throughout the metal, along with a tendency to drift towards the cooler part. This increase in vibration energy and the tendency to drift is communicated to other electrons which in turn pass it on to others. In this way, heat energy is transferred throughout the metal quite rapidly without much displacement of electrons (7). Impurities in metals disturb the conduction of free electrons, which reduces the heat conductivity to a large extent.

Copper has approximately 0.1 percent impurities and has a thermo-conductivity of 2.4×10^2 BTU/hr.ft.F^{o}. (5)

REFERENCES

1. Stroll, M. A., D. J. Hardy. "Study of Thermocouples as Skin Thermometers," Journal of Applied Physiology, 2:534-537, (April, 1950).

2. Goldman, R. F. "The Effects of Football Equipment on Heat Transfer," Physiological Aspects of Sports and Physical Fitness, American College of Sports Medicine and The Athletic Institute, 1968, pp. 38-40.

3. Murphy, R. J., F. W. Asche. "Prevention of Heat Illness in Football Players," Journal of American Medical Association, Vol. 194, (November, 1965).

4. Moore, R. E. "How Crash Helmets Save Lives," New Scientist, 15:288-292, (August, 1962).

5. Kreith, F. Principles of Heat Transfer, International Textbook Co., Scranton, Pennsylvania, 1962, pp. 3-8.

6. Jacob, M. Elements of Heat Transfer, John Wiley and Sons, Inc., New York, 1958, pp. 7-19.

7. Austin, J. B. The Flow of Heat in Metals, American Society for Metals, Cleveland, Ohio, 1942, pp. 11-13.

CHAPTER III

METHODS AND PROCEDURE

Description of the Apparatus

A copper manikin was designed to simulate and standardize the human head form. The manikin had a diameter of approximately 23½ inches and a uniform thickness of 0.032 inches which assured even dissipation of heat. The basic components of the apparatus were: a quartz immersion heater, a thermister, thermocouples, a switch-box, and a Leeds and Northrup Milivolt Potentiometer.

A quartz immersion heater, eleven inches long and five-sixteenths of an inch in diameter, was used. The length of the heater and its resistance to thermal shock made it feasible for this study. The heater was positioned in the front lower half of the manikin to ensure uniform circulation of heat. The heater was easily adapted to this study because the base remained cool while six of its eleven inches provided the heat. The nickel-chrome heater wire operated at approximately 1700° Fahrenheit, providing an excellent source of infrared rays which readily passed through the quartz sheath. The heater could boil 250 milliliters of water in three minutes. The unit drew 400 watts and operated on 115 volts A-C supplied with a cord and plug which was inserted in the thermister.

The thermister was a 3D054 bead-type made by General Electric and was regulated by an electric control unit. The unit controlled temperature to plus or minus one-quarter of a Fahrenheit degree about a set point and was very responsive to temperature change. The time required

to record from one temperature to another was approximately one to two seconds. The thermister was inserted vertically from the side of the base to a depth of approximately one and one-half inches inside the copper manikin head (Figure I).

Temperature measurements were made with thermocouples consisting of #28 gauge copper and constantan wires, overlapped 1 mm. and joined with silver solder. The thermocouples were placed at six specified positions on the manikin and standardized in place by transparent adhesive tape. These six thermocouples were wired in series; a seventh thermocouple was placed in ice water at 32° Fahrenheit and used as a reference point.

The six thermocouples were fed into a switch-box which enabled temperature recordings to be made from each location separately.

Recordings were made on a Milivolt Potentiometer, made by Leeds and Northrup Company, which recorded the various temperatures to one-tenth of a degree. These were taken to the nearest degree Fahrenheit. Room temperature was constantly checked and the potentiometer was standardized accordingly.

A schematic diagram of the component parts of the recording system is shown in Figure II.

Methodology

The copper manikin was filled with water at the three required temperatures of 90°, 110°, and 120° Fahrenheit. After the head was sealed the heater and thermister were plugged into the electrical control unit, the dial was set at the working temperature which then remained constant.

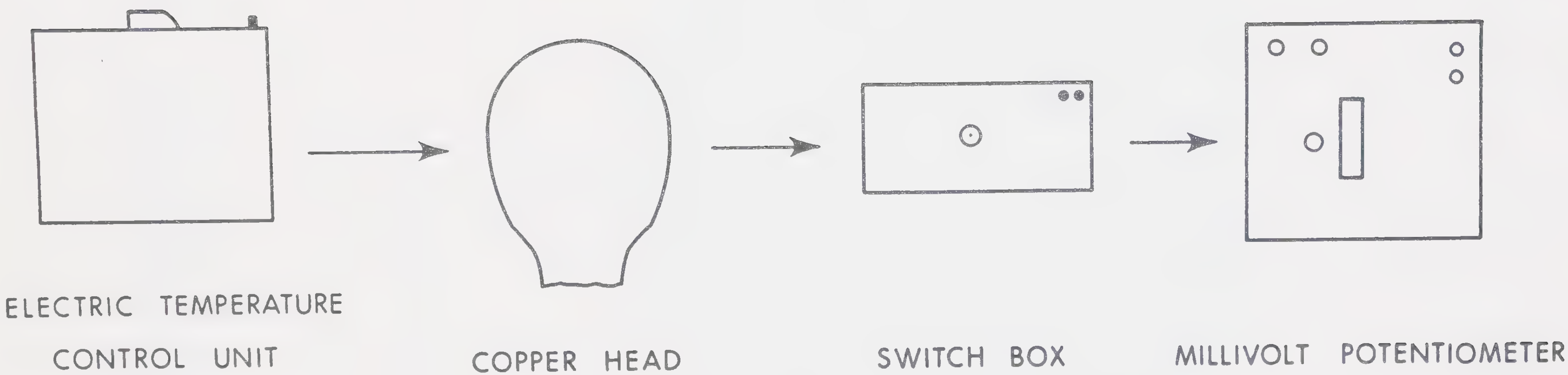

FIGURE 2: RECORDING INSTRUMENTS

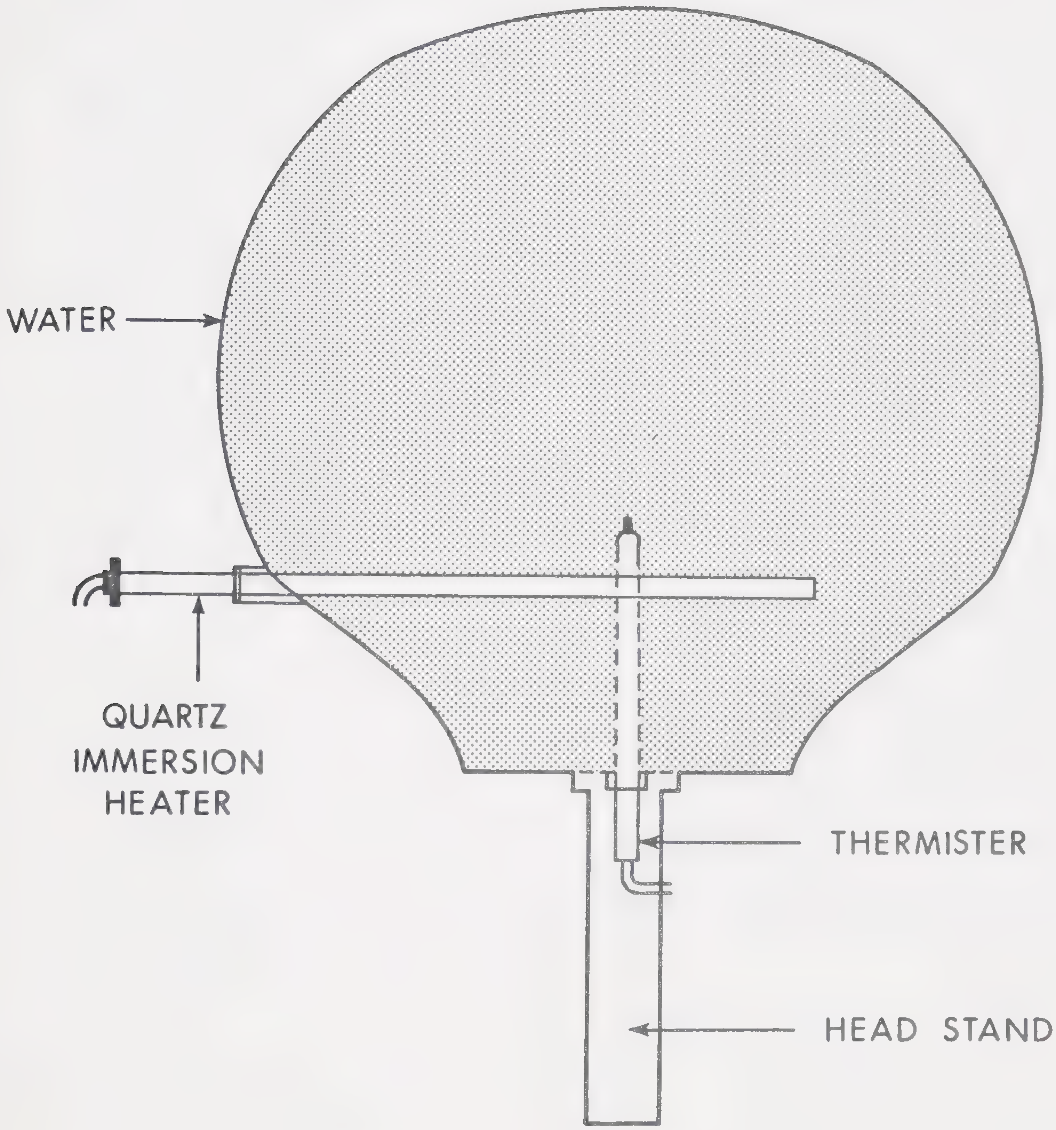

FIGURE 1: SIDE VIEW OF COPPER MANIKIN HEAD WITH INSERTED HEATER AND THERMISTER

The manikin head was then clamped in place on a laboratory stand and its position was standardized. A fan with a wind velocity of approximately 620 feet per minute was placed at a distance of three feet from the manikin. Ten trials were taken on a vane-ananometer to determine wind velocity and the mean was determined.

Ten hockey helmets were then placed on the head and precautions were taken to ensure a uniform fit. Helmets were placed on the manikin for ten minutes, after which the temperature reached a steady-state and was then recorded on the potentiometer. The fan was then turned on for the same period of time and temperatures were once again recorded.

CHAPTER IV

RESULTS AND DISCUSSION

Statistical Analysis

Two-way analysis of variance and Newman-Keuls test on means provided the basis for the statistical analyses. Three two-way analyses of variance were used in the following order: helmets by temperature, helmets by fan, and helmets by position.

Once it had been determined that there were differences in the factors examined, the Newman-Keuls test was used to ascertain significant differences between the ordered means in each analysis. For this study the .05 level of significance was set as the level at which differences between means would be interpreted as significant. In addition, significant differences beyond the .05 level are reported.

A total of twelve temperature readings were taken for each of the ten helmets, six with the fan off and six with it on at the three standard temperatures. To determine the analysis of variance for helmets by temperature, the temperature recordings with fan on and off were combined and treated together in each cell. This analysis is summarized in Table I.

TABLE I

ANALYSIS OF VARIANCE FOR HELMETS BY TEMPERATURE

Source of Variance	S.S.	df	M.S.	F
Helmets	83.00	9	9.22	$6.07 > .01$
Temperature	56840.00	2	28420.00	
Helmets X Temp.	44.00	18	2.44	$1.60 < .05$
Error	503.00	330	1.52	
Total	57470.00	359		

	df	.05	.01
F=	(9,330)	1.91	2.48
	(18,330)	1.64	1.98

The F ratio is not significant at the .05 level for the helmets by temperature and therefore there is not significant interaction between the factors. This means there is no significant difference between helmets at the three selected temperatures of 90, 110, and 120 degrees. A significant F for temperature can be ignored because these temperatures are fixed and will necessarily be significantly different.

The highly significant F value for helmets indicates that there is significant difference between helmets. A Newman-Keuls test was used to determine which helmets differed significantly. A comparison of the ordered mean temperature for helmets is summarized in Table II.

TABLE II

NEWMAN-KEULS TEST ON ORDERED MEAN TEMPERATURES FOR HELMETS BY TEMPERATURE

Order	1	2	3	4	5	6	7	8	9	10
Treatments in Order	3 (DUP)	5 (DUB)	4 (TRE)	6 (WIL)	9 (RID)	2 (CCM)	7 (WIH)	8 (CWM)	10 (RYD)	1 (SPL)
Means	105.69	105.83	106.06	106.61	106.61	106.64	106.69	106.89	107.11	107.17
3	-	.14	.37	.92*	.92*	.95*	1.00*	1.20*	1.42*	1.48*
5		-	.23	.78*	.78*	.81*	.86*	1.06*	1.28*	1.34*
4			-	.55	.55	.58	.63	.83*	1.05*	1.11*
6				-	-	-	.08	.28	.50	.56
9										
2										
7										
8										
10										
1										

* difference significant when greater than Truncated Range r for that order.

Truncated Range r	2	3	4	5	6	7	8	9	10
q.05 (r,100)	2.77	3.31	3.63	3.86	4.03	4.17	4.29	4.39	4.47
q.05 (r,100) $\sqrt{\frac{MS\ error}{pq}}$	.567	.678	.740	.790	.826	.854	.879	.899	.916

Helmets DUP and DUB differ significantly from WIL, RID, CCM, RYD, and SPL and therefore on the basis of their low mean temperatures they differ in heat dissipating qualities. Also, on the basis of the statistical analysis the TRE helmet differs in heat dissipating qualities from helmets CWM, RYD, and SPL. Helmets DUP, DUB, and TRE, however, do not differ from each other.

Analysis of variance was then calculated for helmets by fan at the three set temperatures. The summary of the analysis at 90° is given in Table III.

TABLE III

ANALYSIS OF VARIANCE FOR HELMETS BY FAN AT 90°

Source of Variance	S.S.	df	M.S.	F
Helmets	10.25	9	1.14	6.00 > .01
Fan	12.69	1	12.64	66.78 > .01
Helmets X Fan	10.25	9	1.14	6.00 > .01
Error	19.19	100	.19	
Total	52.38	119		

	df	.05	.01
F=	(9,100)	1.97	2.59
	(1,100)	3.94	6.90
	(9,100)	1.97	2.59

The F ratio for helmets by fan interaction was significant, therefore a test on simple main effects was called for rather than a test on main effects. The test on simple main effects of helmets by fan on showed a

highly significant F value which indicated that there was significant difference in helmets when all observations were made at this level. A Newman-Keuls test was performed for the fan on effect only because the scores for the fan off showed no significant difference. This test is summarized in Table IV.

There is significant difference between DUP helmet and DUB, CCM, WIH, SPL, WIL, RYD, CWM, RID. Also, there is significant difference between TRE helmet and CCM, WIH, SPL, WIL, RYD, CWM, and RID. The DUP helmet differs significantly from SPL, WIL, RYD, CWM, and RID. The CCM helmet differs significantly from WIL, RYD, CWM, and RID. From the analysis there are no significant differences between the DUP and TRE helmets. The DUP and TRE helmets, however, differ significantly from the other helmets in heat dissipating capacity.

The analysis of variance for helmets by fan at 110° is summarized in Table V.

TABLE V

ANALYSIS OF VARIANCE FOR HELMETS BY FAN AT 110°

Source of variance	S.S.	df	M.S.	F
Helmets	32.00	9	3.56	$3.85 > .01$
Fan	39.00	1	39.00	
Helmets X Fan	9.00	9	1.00	$1.08 < .05$
Error	92.00	100	.92	
Total	172.00	119		

	df	.05	.01
F=	(9,100)	2.56	1.97
	(9,100)	2.56	1.97

TABLE IV

NEWMAN-KEULS TEST ON ORDERED MEANS FOR FAN ON EFFECT AT 90°

Order	1	2	3	4	5	6	7	8	9	10
Treatments in Order	3 (DUP)	4 (TRE)	5 (DUB)	2 (CCM)	7 (WIH)	1 (SPL)	6 (WIL)	10 (RYD)	8 (CWM)	9 (RID)
Means	88.33	88.50	89.00	89.17	89.33	89.70	89.83	89.83	90.00	90.00
3		-	.67*	.84*	1.00*	1.37*	1.50*	1.50*	1.67*	1.67*
4			-	.67*	.83*	1.20*	1.33*	1.33*	1.50*	1.50*
5				-	.33	.70*	.83*	.83*	1.00*	1.00*
2					-	.53	.66*	.66*	.83*	.83*
7										
1										
6										
10										
8										
9										

* difference significant when greater than Truncated Range r for that order.

Truncated Range r	2	3	4	5	6	7	8	9	10
q.05 (r,90)	2.81	3.38	3.71	3.95	4.13	4.28	4.40	4.52	4.61
q.05 (r,90) $\sqrt{\frac{\text{MS error}}{pq}}$	.450	.541	.594	.632	.661	.685	.704	.723	.738

The non-significant F ratio between helmets by fan indicated that there was no significant interaction at a temperature of 110 degrees. A significant F value in the helmets was found indicating that a significant difference between helmets existed. A Newman-Keuls test on ordered means was used to ascertain the differences in helmets. This is summarized in Table VI.

At a temperature of 110°, the TRE, DUP, and DUB helmets only differed significantly from the RYD helmet.

The analysis of variance for helmets by fan at 120° is summarized in Table VII.

TABLE VII

ANALYSIS OF VARIANCE FOR HELMETS BY FAN AT 120°

Source of variance	S.S.	df	M.S.	F
Helmets	89.00	9	9.89	$4.89 > .01$
Fan	93.00	1	93.00	
Helmets X Fan	19.00	9	2.11	$1.04 < .05$
Error	202.00	100	2.02	
Total	403.00	119		

	df	.05	.01
F=	(9,100)	1.97	2.56

No significant difference in helmets by fan interaction was found but the F value for helmets was significant to indicate a difference A Newman-Keuls test was used to find the difference in helmets and this is summarized in Table VIII.

TABLE VI

NEWMAN-KEULS TEST ON ORDERED MEANS FOR HELMETS BY FAN AT 110°

Order	1	2	3	4	5	6	7	8	9	10
Treatments in Order	4 (TRE)	3 (DUP)	5 (DUB)	9 (RID)	1 (SPL)	6 (WIL)	7 (WIH)	8 (CWM)	2 (CCM)	10 (RYD)
Means	109.41	109.50	109.50	110.00	110.08	110.08	110.16	110.42	110.50	111.16
4						-	.75	1.01	1.09	1.75*
3							-	.92	1.00	1.66*
5								-	1.00	1.66*
9									-	1.16
1										-
6										
7										
8										
2										
10										

* difference significant when greater than Truncated Range r for that order.

Truncated Range r	2	3	4	5	6	7	8	9	10
q.05 (r,100)	2.81	3.37	3.69	3.94	4.12	4.26	4.39	4.50	4.59
q.05 (r,100) $\sqrt{\frac{MS\ error}{pq}}$	.775	.930	1.02	1.09	1.14	1.16	1.21	1.24	1.27

TABLE VIII

NEWMAN-KEULS TEST ON ORDERED MEANS FOR HELMETS BY FAN AT 120°

Order	1	2	3	4	5	6	7	8	9	10
Treatments in Order	3 (DUP)	5 (DUB)	4 (TRE)	6 (WIL)	9 (RID)	2 (CCM)	7 (WIH)	8 (CWM)	10 (RYD)	1 (SPL)
Means	118.42	118.50	119.50	119.83	119.83	119.91	120.25	120.25	120.25	121.58
3				-	-	1.49	1.83*	1.83*	1.83*	3.16*
5					-	1.41	1.75	1.75	1.75	3.08*
4						.41	.75	.75	.75	2.08*
6							-	.42	.42	1.75
9								-	-	-
2										
7										
8										
10										
1										

* difference significant when greater than Truncated Range r for that order.

Truncated Range r	2	3	4	5	6	7	8	9	10
q.05 (r,100)	2.81	3.37	3.71	3.94	4.12	4.26	4.39	4.50	4.59
q.05 (r,100) $\sqrt{\frac{MS\ error}{pq}}$	1.15	1.38	1.51	1.61	1.69	1.80	1.80	1.80	1.88

In this analysis the WIH, CWM, RYD all had the same temperature means. Therefore, the mean critical value of the three was used to determine if any significant difference existed. In this test the DUP helmet differed significantly from WIH, CWM, RYD, and SPL helmets. Also, the DUB and TRE helmets differed significantly from the SPL helmet.

The results of the analysis of variance of helmets by position is summarized in Table IX.

TABLE IX

ANALYSIS OF VARIANCE FOR HELMETS BY POSITION

Source of variance	S.S.	df	M.S.	F
Helmets	83.00	9	9.22	$.0480 < .05$
Position	45.00	5	9.00	$.0470 < .05$
Helmets X position	39.00	45	.86	$.0045 < .05$
Error	57303.00	300	191.00	
Total	57470.00	359		

	df	.05
F=	(9,300)	2.48
	(5,300)	3.09
	(45,300)	1.40

The F ratio is not significant for any of the factors so no interaction had taken place. This indicated that temperatures recorded for various helmets did not vary according to the position of the thermocouples.

CHAPTER V

SUMMARY AND CONCLUSIONS

Summary

The purpose of this study was to evaluate a random sample of hockey helmets for heat build-up and ability to dissipate heat.

A copper manikin head with built-in heater and temperature regulator, a switch-box, a milivolt potentiometer temperature recorder and fan made up the testing equipment. Hockey helmets were fitted on the manikin head and twelve readings were taken, six with fan off and six with fan on at six standardized positions. Thermocouples located at the six standardized positions registered temperature changes which were recorded on the milivolt potentiometer. The helmets were tested at three set temperatures of 90°, 110°, and 120° Fahrenheit. Helmets were evaluated on the basis of the least temperature build-up at a fixed temperature and how effectively heat was dissipated after the fan was turned on.

Results

Two-way analysis of variance and Newman-Keuls test on means were used in the statistical analysis. The three two-way analyses of variance were used in the following order: helmets by temperature, helmets by fan, and helmets by position. There was significant difference between helmets with the temperature and fan effect. The helmets did not differ according to positions of the thermocouples.

Conclusions

The following conclusions are warranted on the basis of the analysis of the data:

1. A significant difference existed in the heat dissipating qualities of the ten helmets at selected set temperatures of 90°, 110°, and 120° Fahrenheit.

2. Hockey helmets did not tend to vary according to heat dissipation below 90° and seemed to have a wider range of heat dissipation at 120°.

3. Helmets that had the least contact with the manikin or had sparce insulation had greater heat dissipating qualities.

4. There was no difference in the heat dissipating qualities of helmets that had single or multi-piece shells.

5. The Swedish DUB helmet with the plastic suspension had better ventilation and lower mean temperatures than did the RID helmet which had a football suspension.

6. At the temperatures of 90°, 110°, and 120°, the DUP, TRE, and DUB helmets had the lowest mean temperatures and the superior heat dissipating qualities.

BIBLIOGRAPHY

Austin, J.B. The Flow of Heat in Metals, American Society for Metals, Cleveland, Ohio, 1942.

Goldman, R.F. "The Effects of Football Equipment on Heat Transfer," Physiological Aspects of Sports and Physical Fitness, American College of Sports Medicine and The Athletic Institute, 1968.

Intramural Accident Report Files, Faculty of Physical Education, The University of Alberta, 1968.

Jacob, M. Elements of Heat Transfer, John Wiley and Sons, Inc., New York, 1958.

Kreith, F. Principles of Heat Transfer, International Textbook Co., Scranton, Pennsylvania, 1962.

Life, "Hockey," (February 2, 1968).

Minard, D., H.S. Bolding, and J.R. Kingston. "Prevention of Heat Casualties," Journal of American Medical Association, 165:1813, 1957.

Moore, R.E. "How Crash Helmets Save Lives," New Scientist, 15:288-292, (August, 1962).

Murphy, R.S., F.W. Asche. "Prevention of Heat Illness in Football Players," Journal of American Medical Association, Vol. 194, (November, 1965).

Toogood, T., W.G. Love. "Hockey Injury Survey," Journal of the Canadian Association for Health, Physical Education and Recreation, 32:20-23, (January, 1966).

White, C.A. Personal Correspondence, March 1967.

APPENDIX A

LIST OF HOCKEY HELMETS

HELMETS USED IN STUDY

Order	Code	Manufacturer	Model	Retail Price
1	SPL	Spalding	HH5	$4.90
2	CCM	CCM	1 Model	5.50
3	DUP	Perdix-Dunlop	1 Model	7.00
4	TRE	Trekronor		8.00
5	DUB	Dubbelum	VW	7.00
6	WIL	Winwell		7.00
7	WIH	Winwell		8.00
8	CWM	Cooper	SK 12	9.75
9	RID	Riddell	H - 110	20.00
10	RYD	Riddell		

APPENDIX B

DESCRIPTION OF HOCKEY HELMETS

DESCRIPTION OF HELMETS

<u>SPL</u>

Mould: one-eighth inch plastic (polyethylene)

Fit: adjustable two-piece

Insulation: three-sixteenth inch leather-covered plastic foam

Ventilation: five narrow openings in front and back

<u>CCM</u>

Mould: one-eighth inch plastic (polyethylene)

Fit: adjustable two-piece

Insulation: one-quarter inch foam

Ventilation: one row of small vertical openings in front and double row on top and back.

<u>DUP</u>

Mould: one-sixteenth inch plastic (polyethylene)

Fit: adjustable two-piece

Insulation: rubber pads at front, back, and sides

Ventilation: sectional space on top and two triangular openings on the back

<u>TRE</u>

Mould: three-sixteenth inch plastic (polyethylene)

Fit: adjustable two-piece

Insulation: three-quarter inch leather covered foam pads on front, top, and back. Thin pads on the side

Ventilation: staggered vertical openings along sides and back

<u>DUB</u>

Mould: three-sixteenth inch plastic (polyethylene)

Fit: one-piece

Insulation: plastic suspension with foam pads on the side

Ventilation: triangular openings encircling the helmet

<u>WIL</u>

Mould: one-sixteenth inch plastic (polyethylene)

Fit: adjustable three-piece

Insulation: one-quarter inch foam

Ventilation: small circular openings at the front, top, and back

<u>WIH</u>

Mould: one-eighth inch plastic (polyethylene)

Fit: adjustable two-piece

Insulation: one-quarter inch rubber pads along front, back and sides

Ventilation: squared openings in single rows on the front, top, and back

<u>CWM</u>

Mould: one-eighth inch plastic (polyethylene)

Fit: adjustable three-piece

Insulation: rubber lined with leather

Ventilation: small circular openings along front, top, and back

RID

Mould: three-sixteenth inch durable plastic

Fit: one-piece

Insulation: cotton webbing used in suspension system

Ventilation: four large circular holes

RYD

Mould: three-quarter inch rubber-covered foam

Fit: one-piece

Insulation: polished rubber covering foam

Ventilation: small circular holes perforating whole helmet

APPENDIX C

RELIABILITY DATA

TABLE A

PRE - TEST

RAW RELIABILITY DATA

Helmet	Fan	Position of Thermocouple				Position of Thermocouple				Position of Thermocouple			
		1	2	3	4	1	2	3	4	1	2	3	4
TRE	Off	111	110	110	111	111	110	110	111	111	110	110	111
	On	110	109	110	110	110	109	110	110	110	109	110	110
RID	Off	110	110	110	111	110	110	110	111	110	110	110	111
	On	110	110	110	110	110	110	110	110	110	110	110	110
RYD	Off	111	111	112	111	111	111	112	111	111	110	110	111
	On	110	110	110	109	110	110	110	110	110	109	110	110

APPENDIX D

RAW DATA

TABLE A

TEMPERATURE AT 90^{o}

Helmet	Fan	Position					
		1	2	3	4	5	6
SPL	Off	90	90	90	90	90	90
	On	90	90	90	89	90	89
CCM	Off	90	90	90	90	90	90
	On	90	89	90	89	89	88
DUP	Off	90	90	90	90	90	90
	On	88	89	89	89	88	87
TRE	Off	90	90	90	90	90	90
	On	90	88	89	89	88	87
DUB	Off	90	90	90	90	90	90
	On	88	89	89	89	90	89
WIL	Off	90	90	90	90	90	90
	On	90	89	90	90	90	90
WIH	Off	90	90	90	90	90	90
	On	90	90	90	89	89	88
CWM	Off	90	90	90	90	90	90
	On	90	90	90	90	90	90
RID	Off	90	90	90	90	90	90
	On	90	90	90	90	90	90
RYD	Off	90	90	90	90	90	90
	On	90	90	90	90	90	89

TABLE B

TEMPERATURE AT 110°

Helmet	Fan	Position					
		1	2	3	4	5	6
SPL	Off	110	110	111	110	111	111
	On	110	110	110	108	110	110
CCM	Off	112	111	111	111	111	111
	On	110	110	111	110	110	108
DUP	Off	110	110	110	111	112	110
	On	105	108	108	110	110	110
TRE	Off	110	110	110	111	110	110
	On	110	108	110	110	109	105
DUB	Off	111	110	110	110	110	111
	On	108	110	110	108	110	106
WIL	Off	111	110	111	110	111	111
	On	110	110	111	109	110	107
WIH	Off	111	110	111	110	110	110
	On	110	110	111	110	110	109
CWM	Off	111	111	111	110	110	111
	On	110	110	111	110	110	110
RID	Off	110	110	110	111	110	110
	On	110	110	110	110	109	110
RYD	Off	112	112	112	112	112	112
	On	110	111	112	110	110	109

TABLE C

TEMPERATURE AT 120°

Helmet	Fan	Position					
		1	2	3	4	5	6
SPL	Off	123	122	122	121	121	123
	On	123	122	122	120	120	120
CCM	Off	121	120	121	120	121	121
	On	120	120	120	118	118	118
DUP	Off	120	120	120	120	120	120
	On	119	120	119	117	115	111
TRE	Off	122	120	120	121	120	120
	On	120	117	120	120	119	115
DUB	Off	120	120	120	120	120	120
	On	118	119	116	117	120	112
WIL	Off	121	120	121	121	121	121
	On	120	120	120	118	120	115
WIH	Off	121	121	121	121	121	121
	On	120	120	120	119	120	118
CWM	Off	121	121	121	121	121	121
	On	120	120	120	119	120	118
RID	Off	120	120	120	121	120	120
	On	120	119	119	120	120	119
RYD	Off	121	121	121	121	121	121
	On	121	120	121	120	120	115